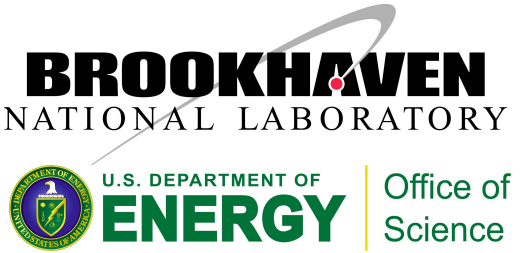
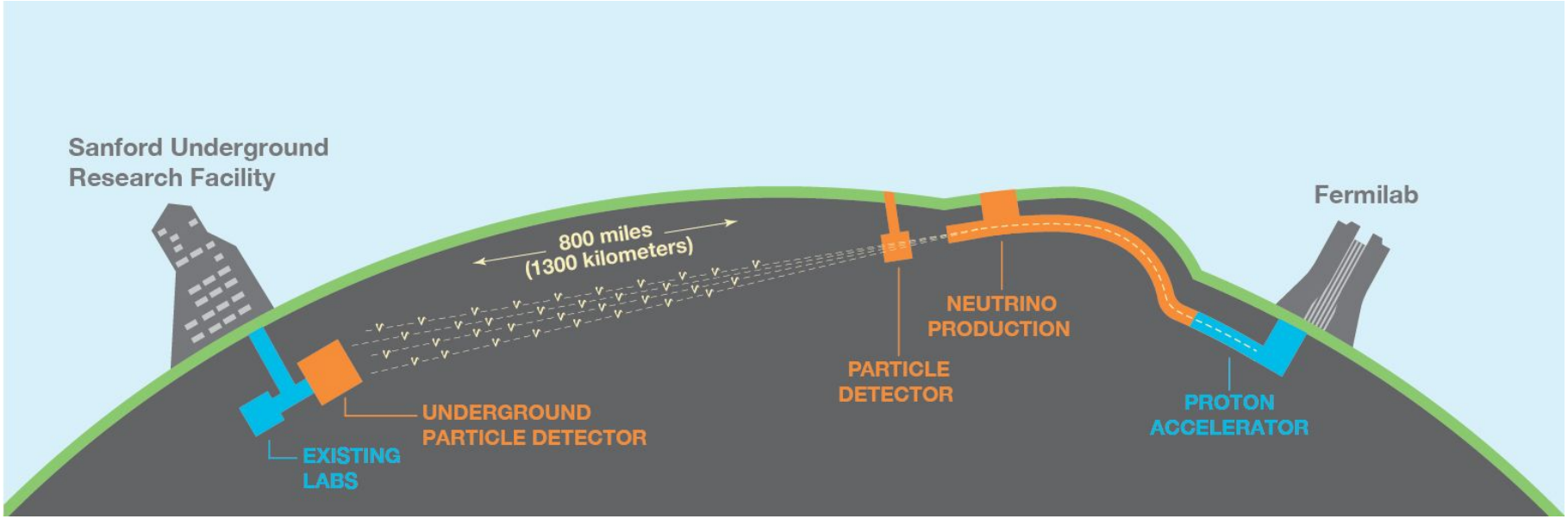
protoDUNE-SP Cold Electronics Quality Control

DPF - July 31, 2017



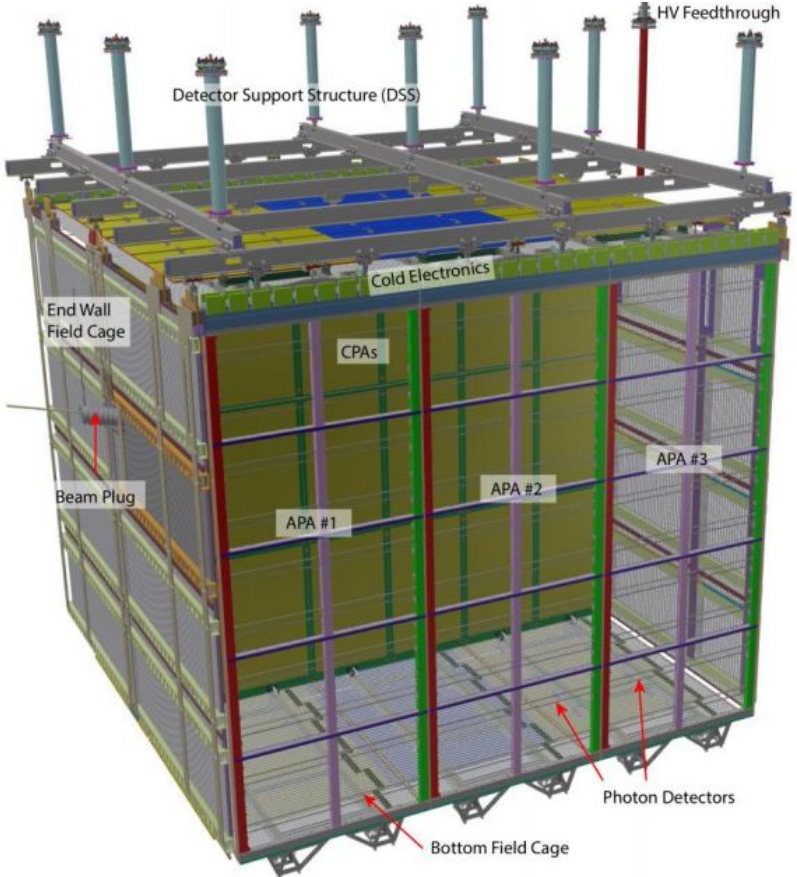
B.Kirby for the DUNE Collaboration

Deep Underground Neutrino Experiment (DUNE)



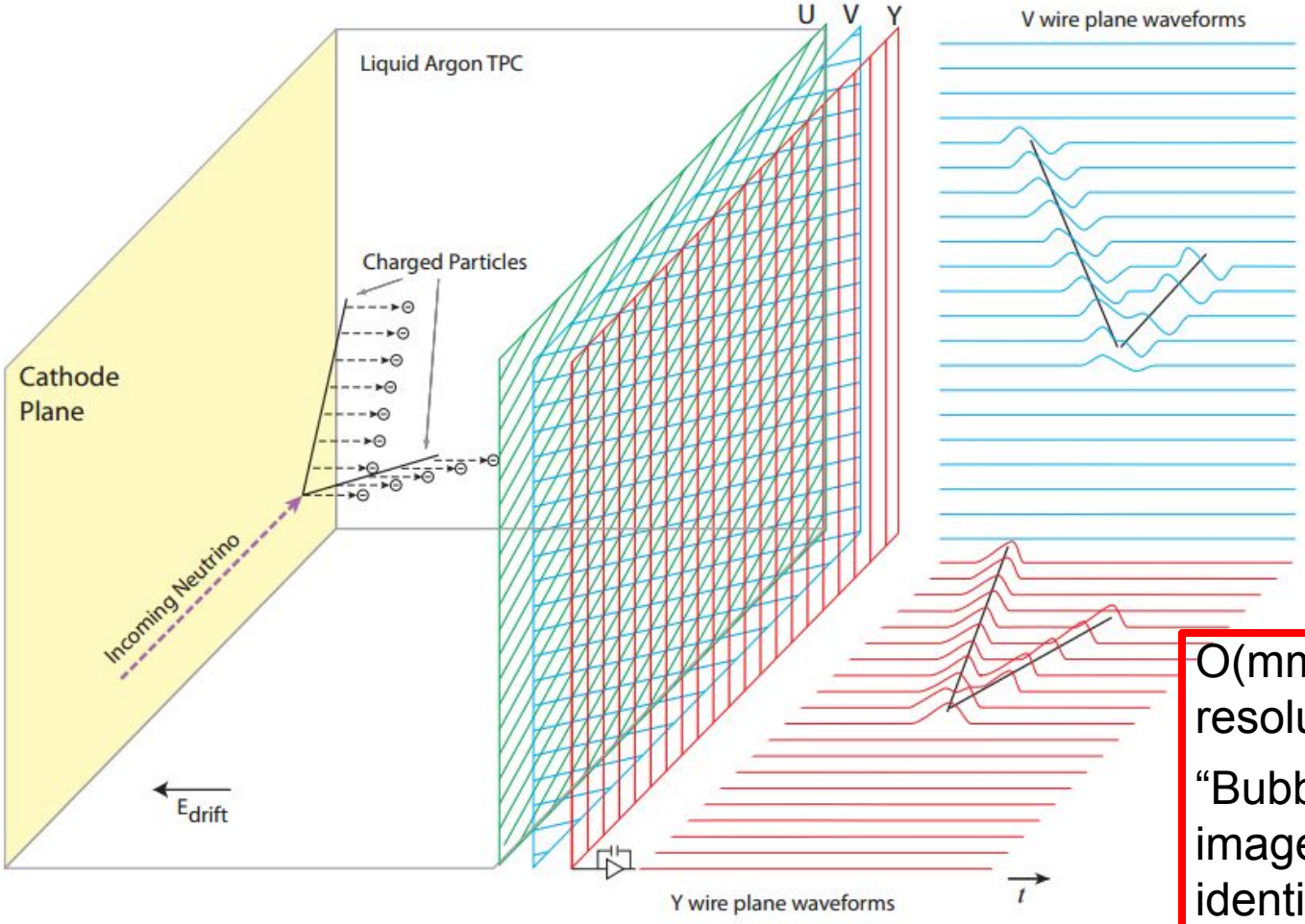
- Long-baseline neutrino oscillation experiments measure ν_e appearance amplitude and constrain neutrino mixing parameters
- Deep Underground Neutrino Experiment (DUNE) is a next-generation neutrino oscillation experiment
- 1300km baseline and 40kt active target mass

protoDUNE Single Phase Prototype



- protoDUNE-SP is large-scale prototype of DUNE single-phase Liquid Argon Time Projection Chamber (LArTPC)
- 15360 individually instrumented TPC wires in Anode Plane Assemblies (APAs) in 0.77kt LAr cryostat
- Low noise cold electronics operate at cryogenic temperature inside the cryostat
- **Goal: demonstrate performance and stability of DUNE single-phase far detector design**

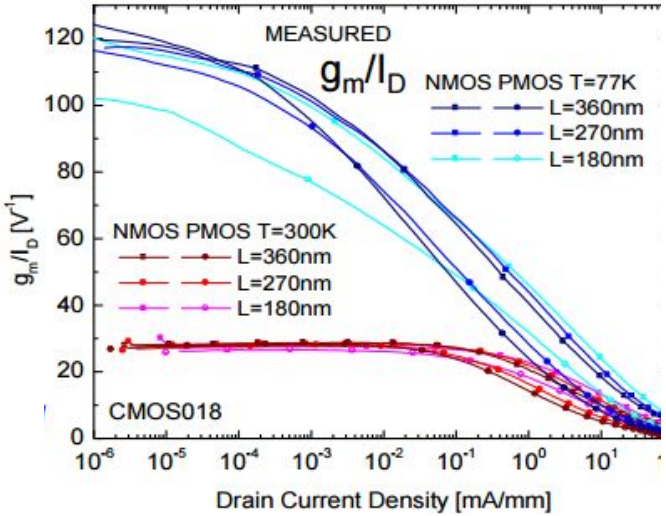
Liquid Argon Time Projection Chambers (LArTPCs)



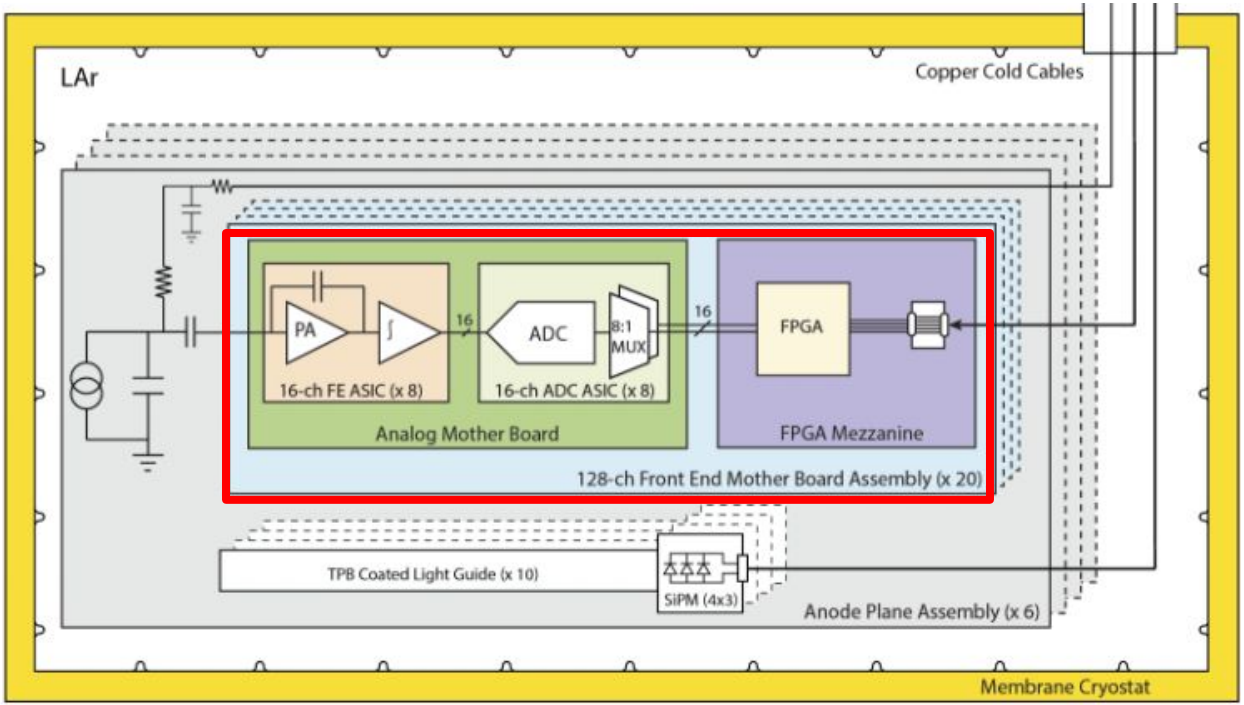
O(mm) scale 3D position resolution for large volumes!

"Bubble chamber"-like images enable background identification

DUNE/protoDUNE Cold Electronics Overview



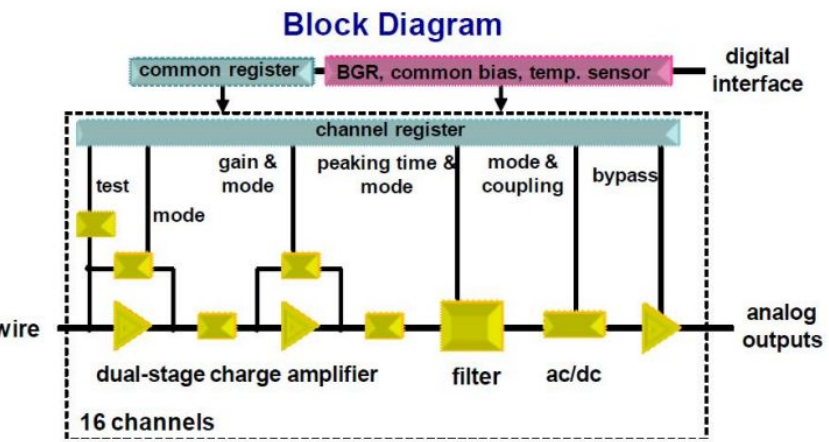
$$ENC \approx \frac{dC_d}{q}\sqrt{\frac{kT}{3\tau_s g_m}}$$

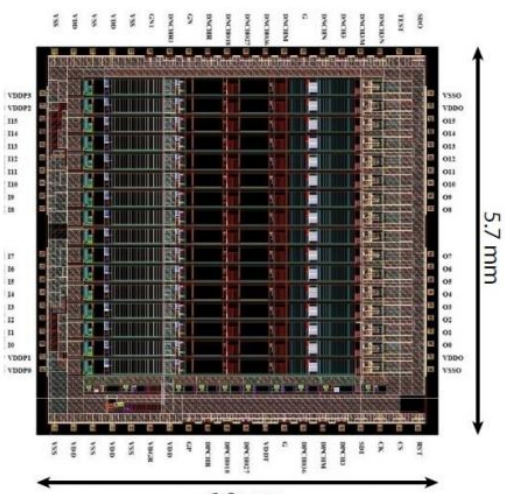


- Cold preamps located inside the cryostat reduces electronic noise
- Cold sampling and digital logic coordinates readout and simplifies cabling
- Implemented in compact Front End Mother Board (FEMB) integrated wire readout

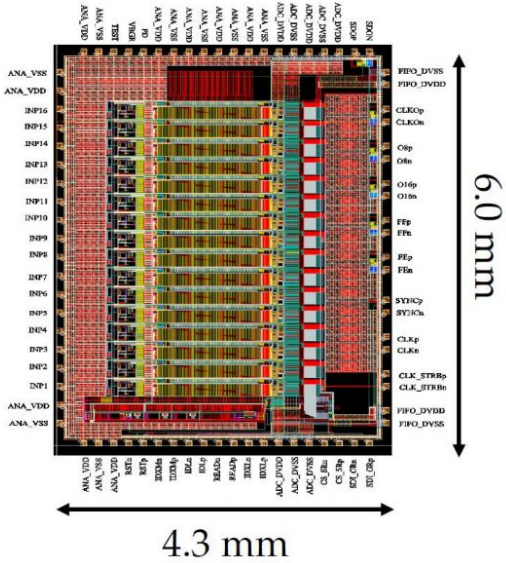
Cold Electronics Front End and ADC ASICs

Cold Preamp-Shaper ASIC



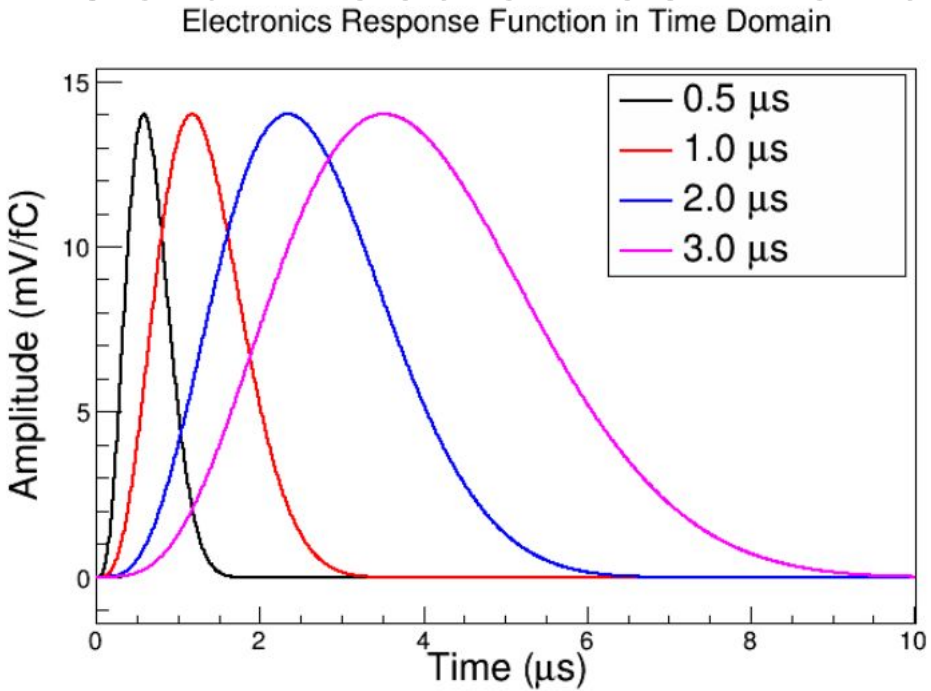


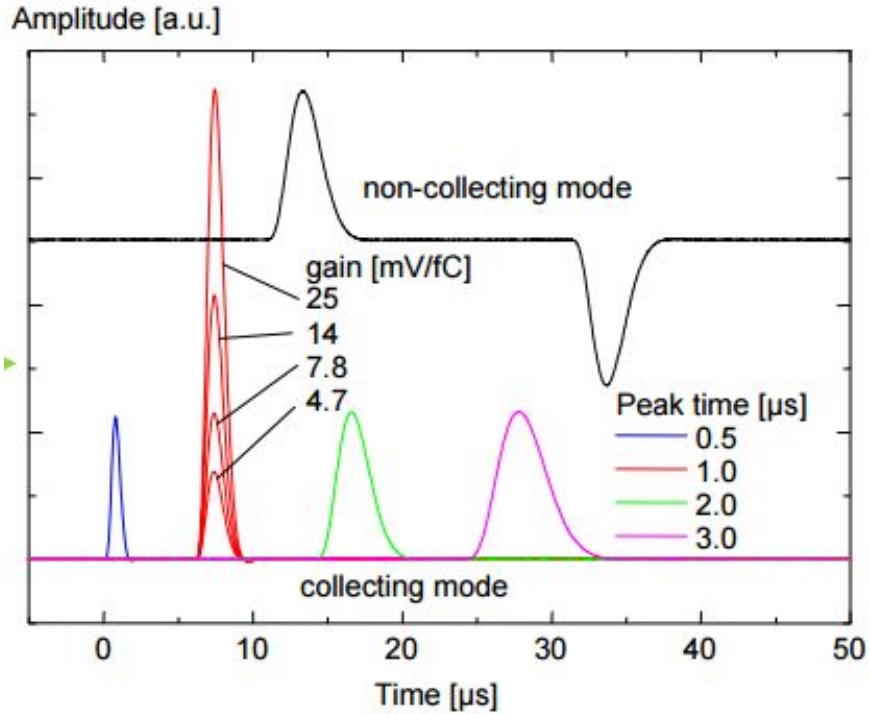
Cold ADC ASIC



- 16 channel preamp+shaper Front End ASIC (FE-ASIC)
  - Designed for low-noise cryogenic operation, long lifetime
- 16 channel digitizing ADC ASICs sample at 2MHz, 8:1 serialization

Cold Electronics Front End ASIC Response



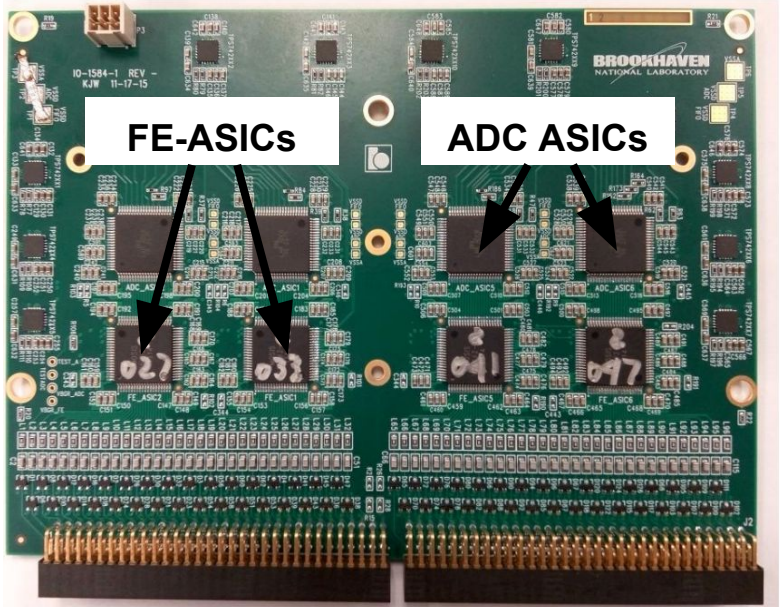


- Cold ASIC response well matched to LAr electron drift speed of ~1.1mm/us
- < 1000e- Equivalent Noise Charge (ENC) at 77K (MIPs signals >10000e-)

Cold Electronic FEMBs

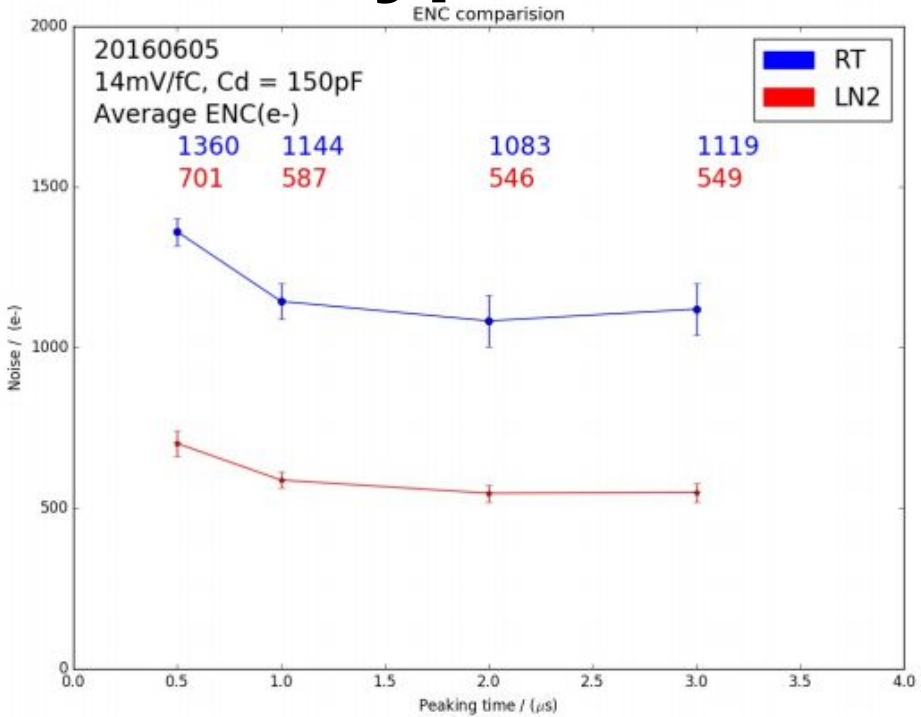
- **Front-End Motherboards (FEMBs)** integrate analog, digital electronics
- **Analog board:** 8 pairs of shaping-amplifier ASICs and digitizing ADC ASICs
- **FPGA board**: Programs and coordinates ASIC operation and readout, multiplexes and streams data to backend through GB transceivers

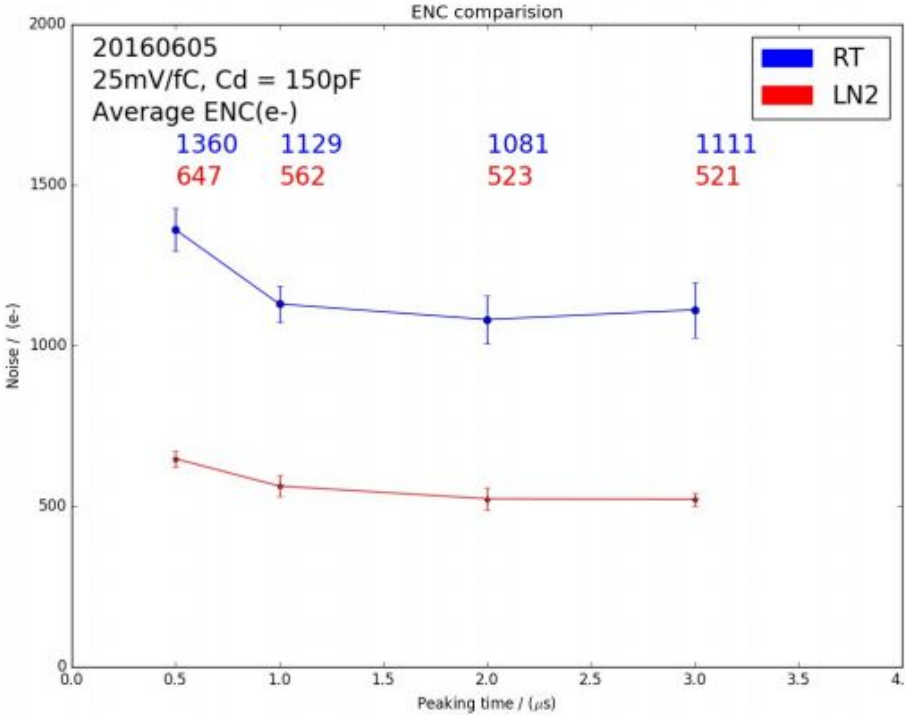
Analog and ADC Board



SBND/protoDUNE FEMB

Prototype FEMB Noise Performance





- protoDUNE FEMB prototype has excellent cryogenic noise performance with ~500e- ENC!

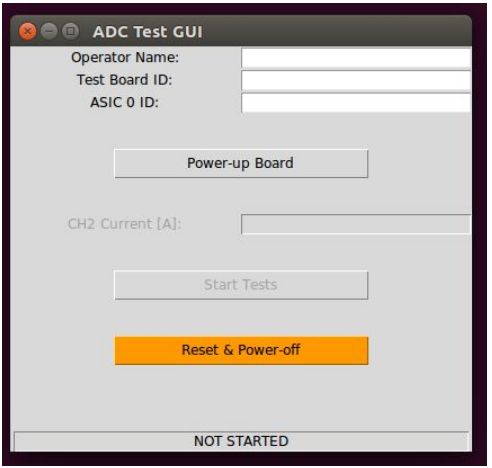
protoDUNE-SP Electronics Production Tests

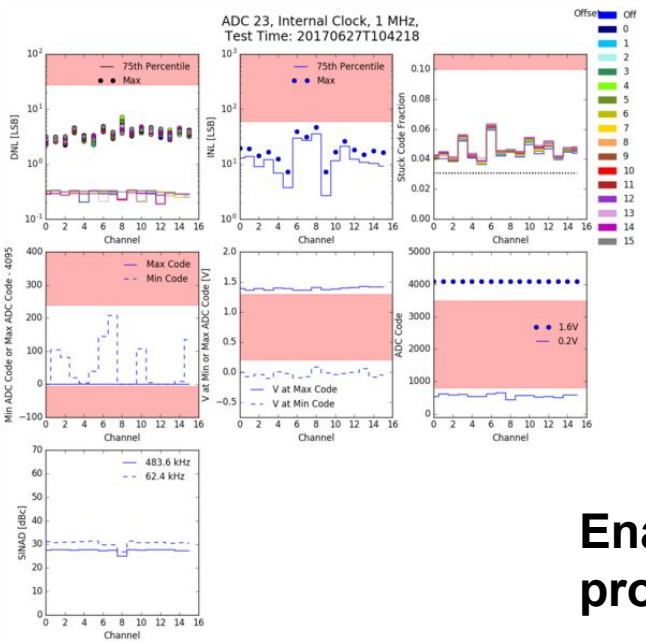
- protoDUNE-SP design has 15360 readout channels
  - 960 FE-ASICs, 960 ADC-ASICs, 120 FEMBS
- Cryogenic operation requires cryogenic screening and performance validation tests for many components
- **Significant production quality control effort required**

Component	Validation Requirement
100 MHz Electronic Oscillators (FEMB)	Cryogenic screening
Front End ASIC	Cryogenic screening of 10% of production
ADC ASIC	Cryogenic performance measurement
Integrated FEMBs	Cryogenic performance validation

Electronics Production Test Software

Example ADC ASIC Test GUI and Online Summary Plots





- Production electronic test processes and validation data-taking controlled by [python-based software package]
  - Automated data-taking
  - Online analysis, archiving
  - Simplified interface for shifters
  - Full documentation of test procedures and reproducibility via version control

Enables systematic evaluation of protoDUNE electronics production

ADC ASIC Chip Tester

ADC ASIC Chip Tester

ADC ASIC Chip with ASIC Immersed in Liquid Nitrogen

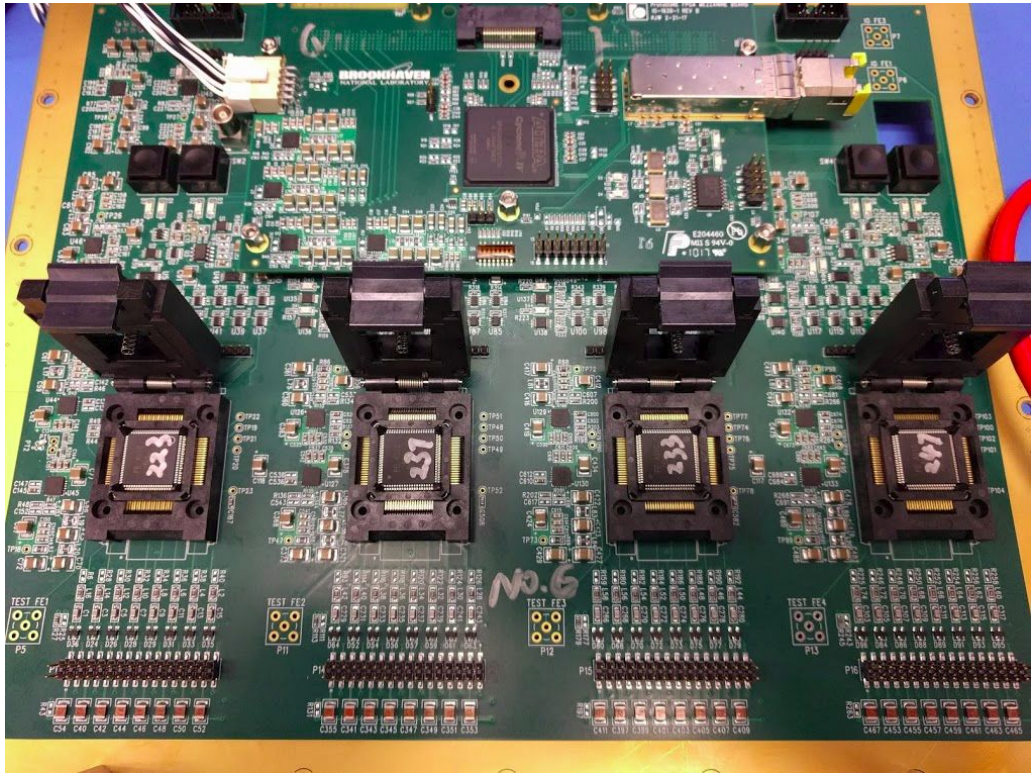
- Validate ADC ASICs at room and cryogenic temperature
- Socket board has single socket for ADC ASIC
- FPGA board controls and reads out ADC ASIC, controls ethernet interface to readout software

ADC ASIC Quad-Chip Tester

Integrated FE-ASICs

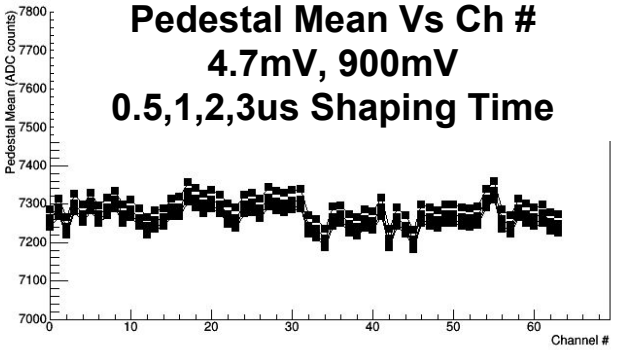
- Validate 4 ADC ASICs simultaneously at room and cryogenic temperature
- Measure DNL, INL, identify bad channels etc
- Verify SPI configuration, basic ASIC functionality
- 4 integrated FE-ASICs provide realistic signals

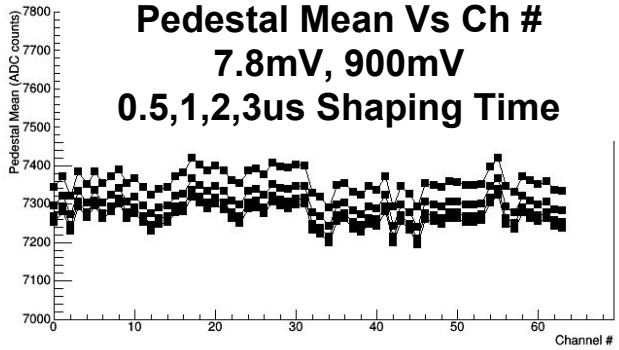
Front-End ASIC Quad-Chip Tester

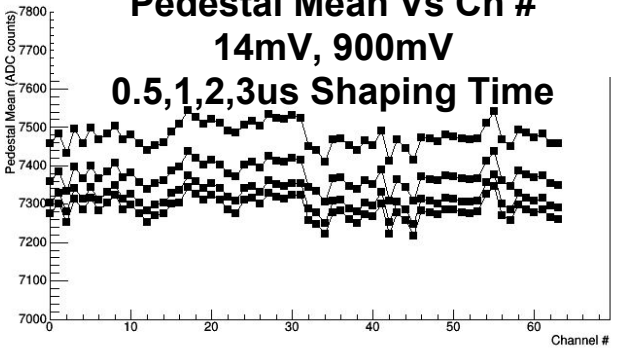


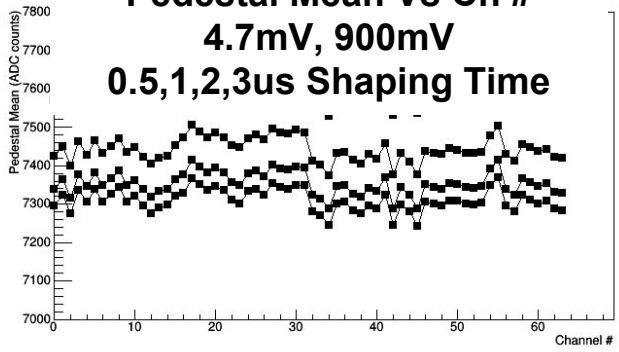
- Quad-chip tester similarly qualifies FE-ASICs
- Multiple calibration sources
- Measure cryogenic performance channel pedestal, gain, ENC etc
- Verify SPI configuration, internal ASIC DAC

Example Quad FE-ASIC Test Summary Plots







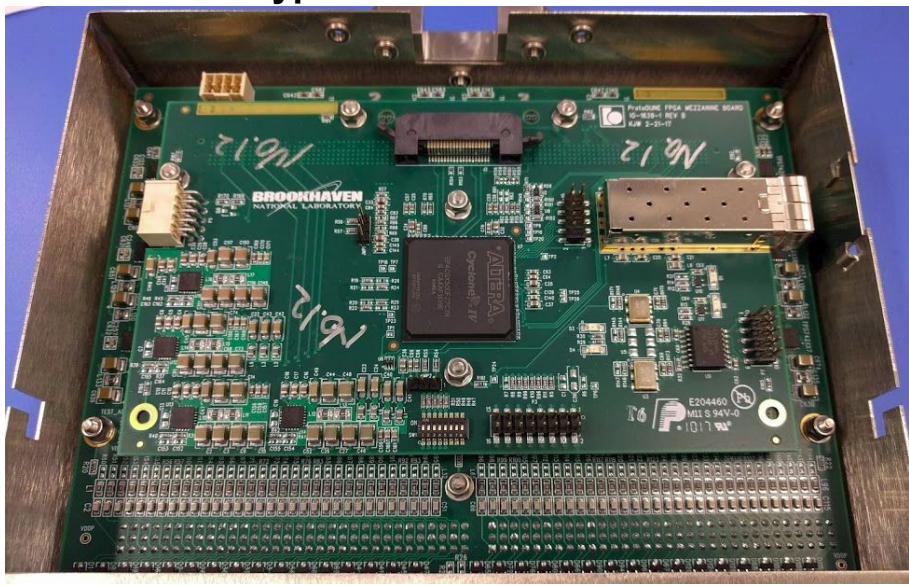


- Measure performance of 128 channels at a time
- Identify bad chips/channels with z-score selection cuts

FEMB Cryogenic Test Stand

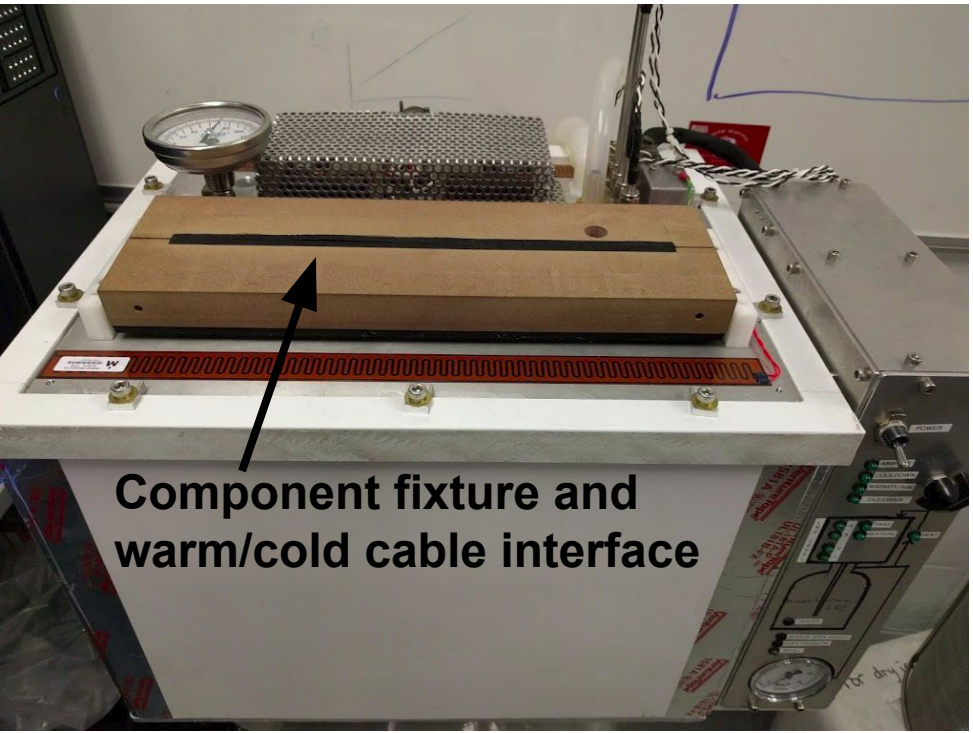
WIB Reading out 4 FEMBs in Dewar

Prototype FEMB in “Cold Box”



- Integrated FEMBs and associated cables are tested at room and cryogenic temperature, up to 4 at a time
- Use full protoDUNE Warm Interface Board (WIB) readout

MSU Cryogenic Test Chamber



- Consistent cryogenic cooling and condensation are significant challenge for production quality control
- Cryogenic test chamber automatically cools and immerses components in LN2
- Warm-up process minimizes condensation, simplifies test procedure

Initial FE and ADC ASIC Production Results

FE ASICs

- 268 production FE-ASICs tested early June 2017 at room temperature
  - Only 2 ASICs identified as bad (single bad channel)
  - Very high yield!
- Cryogenic tests ongoing, expect only 10% of production require individual cryogenic qualification

ADC ASICs

- 367 ADC ASICs cryogenically tested and performance ranked
- Subset selected for protoDUNE APA1

Conclusions

- protoDUNE is an important prototype testing DUNE-style detector and cold readout electronics
- Cold electronics production testing is underway **NOW**
- Dedicated test-stands and automated software well-suited to fully validate production protoDUNE cold electronics, verify cryogenic performance